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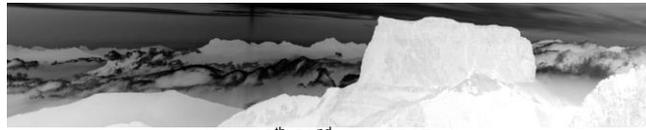
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Wastewater monitoring to study the temporal and spatial representativeness of flow and pollution discharge measurements

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ABSTRACT

Measuring flow-rate and pollutant discharges through sewer networks is required for legal, technical and management reasons. This paper presents an experimental study combining continuous monitoring of flow and water quality parameters with studies of the velocity and suspended solids spatial distribution in order to understand both the question of temporal and spatial representativeness of continuous measurements. The experimental site has been chosen to investigate the situation in both a uniform and a complex situations, it is formed by the junction of two channels. Three measurement points were selected: upstream, downstream and at the junction. Firstly, the context of this project is reported, secondly the experimental investigations and data validation procedure are detailed and finally the results are presented and discussed. Logical and statistical automated methods were used to validate data. The necessity of the application of data validation procedure was proved for faulty data detection and faulty data correction. The ranges of quantity (heights, velocities and so flow rates) parameters were determined using continuous monitoring. Some trend evolutions and ranges were noted for temperature, conductivity, pH.

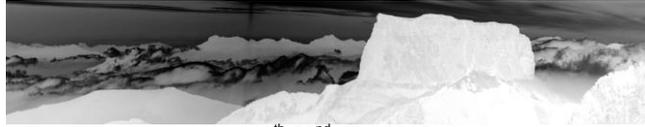
KEYWORDS

Monitoring, velocity, suspended solids, sediment, sewer.

1 INTRODUCTION

A good management of wastewater systems requires a better understanding of flow rates and pollutant loads discharge at both event and annual scales. Besides its compliance with the French national regulations (interministerial decree of 22 June 2007) the implementation of a continuous diagnosis of the sewage system provides necessary tools to understand and improve the functioning of the sewage network, and at the same time, a mean to reduce untreated discharges pollutants into receiving waters. Therefore, Delleur (2001) and Ashley et al., (2004) indicated that improvement of knowledge cannot be achieved without continuous measurements over a long period. In practice, the challenge lies in the ability of the instrumentation to provide representative information of the process. This representativeness should be both temporal and spatial as urban collectors may have cross sections of several square meters whereas the sensors give mainly punctual information.

Moreover, the harsh environment inside sewers reduces the ability of sensors to measure. This may cause that the measurand have a poor quality in terms of availability, reliability and accuracy. In addition to the possible measurement uncertainty related to the sensor performance itself, errors can occur due to various reasons such as the sensor installation problem or the battery failure etc (NF ISO/CEI, 2011). Therefore, these values provided by a sensor, called raw data, need to be validated. Data validation is a method to identify abnormal conditions related to malfunctions in measurement systems especially those related to sensors and to replace doubtful data (Mourad et Bertrand-



Krajewski, 2002). Branisavljevic et al. (2010) indicated that un-validated data can lead in wrong conclusions and erroneous decisions because raw data may include errors such as noise, drift, outliers, malfunctions, etc. The amount of data collected in long-term campaigns is usually very large. Therefore, manual validation is very time consuming and possibly inaccurate. Thus, it would be useful to develop semi-automatic or automatic data validation procedures that can assist the user in monitoring and processing the incoming data.

This study is part of the national project MENTOR that involves ten teams of both academics and sewer management services to take benefit of interactions between human sciences but also numerical modelling and experimental investigations to improve sewer metrology. This paper focus on the experimental part of the project. It presents the wastewater monitoring to study the temporal and spatial representativeness of flow and pollution discharge measurements to improve our understanding of the dynamics of pollutants in wastewater systems. The acquired data will be used by another team of the MENTOR project in order to contribute to the numerical modeling with understanding and managing the hydraulic functioning and helping instrumentation of sewer networks. Firstly, the experimental site and its instrumentation are presented. Second, data validation procedure is detailed and some examples of its application are illustrated. Finally, the results are detailed and discussed.

2 EXPERIMENTAL SECTION

2.1 Experimental site and instrumentation

Several experimental studies on the distribution of velocities and TSS concentrations were conducted in uniform compound sections and for sites without sedimentation in the Nantes region (North western France). These works (Larrarte; 2006, 2008, 2015) have shown the complexity of velocity fields with the presence of the maximum velocity below the free surface and also an area of strong velocity gradients near and above the bank. The results showed that, for suspended solids, concentration fluctuations may exist but no vertical gradient have been shown on those sites. Transverse concentration gradients were noted for velocities of the order of 0.5 m/s, therefore below the threshold of self-cleansing. Vertical concentration gradients were observed on a site with a presence of a thick muddy layer and a low velocity (about 0.10 to 0.15 m/s) (Hemmerle et al., 2004). These findings guided the choice of complementary investigations in order to:

- investigate for which hydraulic contexts, vertical concentration gradients could be observed,
- corroborate or not the existence of transverse gradients.

2.1.1 Site characteristics

In order to meet the objectives of the MENTOR project, the question of both temporal and spatial representativeness have to be investigated. We have developed an approach combining continuous monitoring of flow and water quality parameters with studies of the velocity and suspended solids distribution. The site is located in Nantes, in the northwest part of France. It is encompassed within a watershed called Barbusse which is in the northeastern sector of the center. It is a mixed residential area and economic activities with a high urbanization. Its surface is 175.4 ha for about 15,000 population equivalents. The waterproofing coefficient of this watershed is between 50 and 60%. It is structured by roads and areas with services and shops. It also includes major green spaces and a few parks. The Nantes climate is temperate oceanic, characterized by frequent and prolonged rains, but fairly low intensity. The average slope of the sewer invert is 1%.

In order to study the temporal representiveness, flow rates and wastewater quality are continuously monitored to acquire data over a long period. Doppler flowmeters (ISCO model 2150) are used for



monitoring velocity and water level. Wastewater quality is continuously monitored for turbidity (Solitax sc Hach Lange), conductivity (Hach Lange 3700sc) and pH (Hach Lange pH-SC). Turbidity, conductivity and pH sensors are installed so that the probes are protected in a sock to limit their fouling and clogging. They are immersed in a fixed position in the wastewater in the center of the flow.

The time step for data recorded is 5 minutes for all sensors. This time step is recommended to better reproduce the trend of hydrological phenomena, especially for modeling applications (Versini et al., 2015). All data are time-stamped and synchronized to CTU (Coordinated Universal Time). The maintenance and the cleaning of sensors, as the data collection are carried at least once every two weeks. Flowmeter data collection is done directly on the site using the Flowlink software by connecting a laptop to the flowmeter housing. Turbidity, conductivity and pH sensors are connected to a multi-parameter controller (Hach Lange SC 1000) in the technical room where the data transmission is managed.

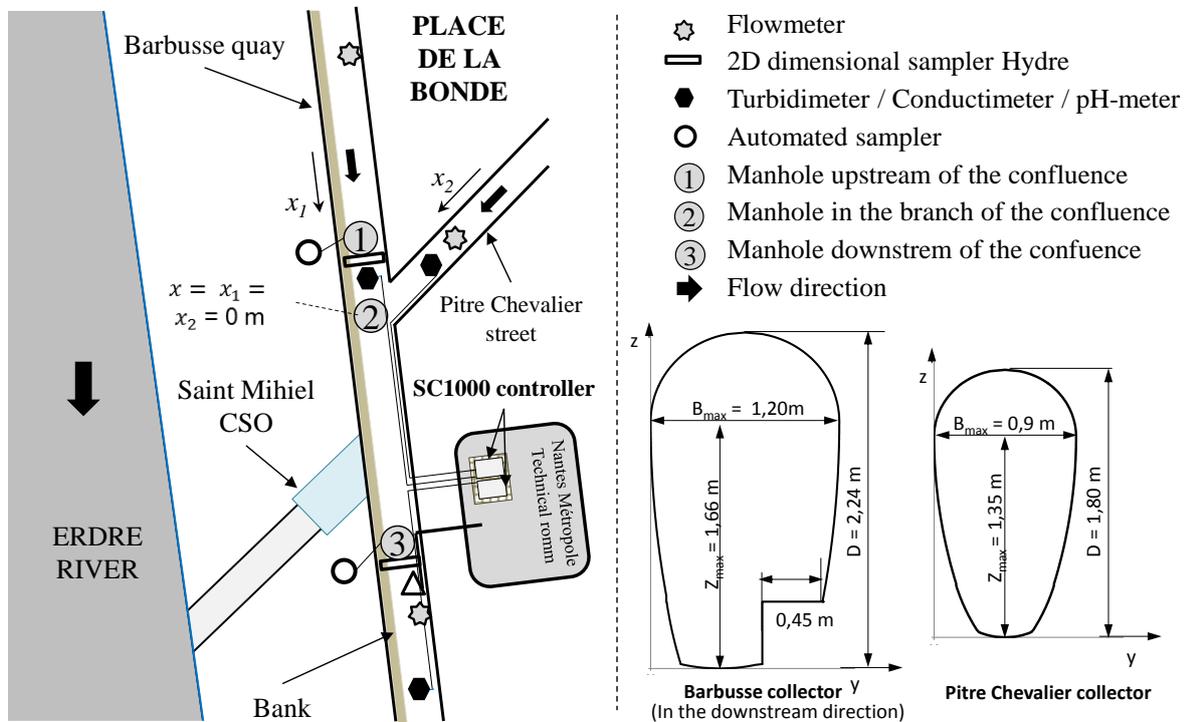
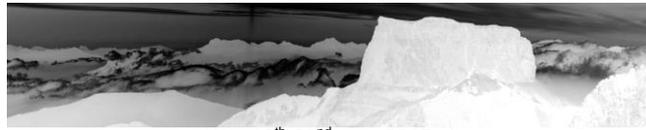


Figure 1: Scheme and instrumentation of the experimental site

2.2 Procedure for data validation

Data validation process usually consists of two main steps: faulty data detection and faulty data correction. Faulty data detection identifies doubtful values or errors in data and the correction process provide methods to deal with doubtful data. We followed the classification proposed by Mourad and Bertrand-Krajewski (2002) for data validation. This method classifies the data into three classes: A for reliable values, B for doubtful values and C for faulty, missing, outlying or aberrant values based on several automated tests.

We have developed automatic pre-validation tools using Excel macro depending on the type of instrument. Figure 3 shows the workflow for data validation. For pH, conductivity and turbidity



sensors, calibration functions taking into account the uncertainties related to sensors are applied to the raw data before applying all pre-validation tests. Then, specific faulty data detection tests and data correction methods are carried out for raw data and calibrated data. At the end of the application of automatic pre-validation tests, an overall mark denoted NG is assigned automatically to each data. This mark is the worst partial mark for each parameter at time t. It is determined as follows: if all the Ni partial values are A, NG overall mark is A; if a Ni partial mark is B, the NG overall mark is B; if a Ni partial mark is C, the NG overall mark is C (Figure 2). The Figure 2 shows an example of overall mark assignment of a portion of branch velocity data. The final validation is carried out manually by the operator and end with only two marks: valid (mark A) or not valid (mark C). All information on applied pre-validation tests and post processing is saved in the same Excel file. This allows tracing all modifications and process treatments applied to the raw data. The raw data themselves are always kept unchanged. Each validation file processes monthly data.

Date	Velocity raw data (m/s)	Physical range	Maintenance duration	Frequent range	Signal gradient	NG	Comment
		N1	N2	N3	N4		
10/17/14 13:55	0.285	A	A	A	A	A	Valid
10/17/14 14:00	0.266	A	A	A	A	A	Valid
10/17/14 14:05	0.272	A	A	A	A	A	Valid
10/17/14 14:10	-0.125	C	A	B	A	C	Outside the physical range
10/17/14 14:15	-0.125	C	A	B	A	C	Outside the physical range
10/17/14 14:20	-0.125	C	A	B	A	C	Outside the physical range

Figure 2: Example of overall mark assignment of velocity values

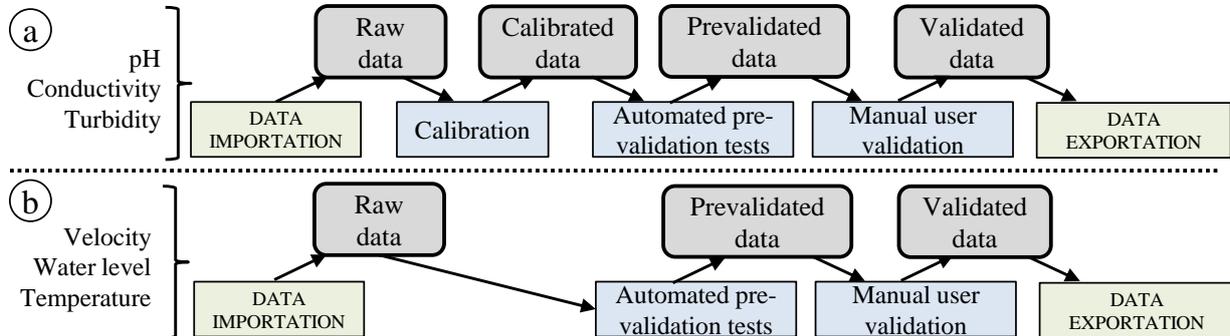
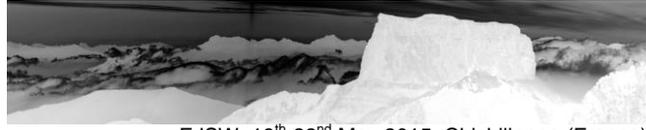


Figure 3: Proposed validation procedure

Pre-validation tests, including both faulty data detection methods and faulty data correction methods used in this study are given in the following:

2.2.1 Physical range check:

The measured values cannot exceed a physical range with a given sensor in a given location. It is both sensor and site specific. The aim of this test is to identify any measured value outside the sensor measurement range. These values will be marked C. For instance, the physical range of upstream water level is from 0.025 to 2.24 m. The minimum threshold 0.025 m corresponds to the typical minimum depth which can be measured by the ISCO 2150 flowmeter and the maximum threshold 2.24 m corresponds to the maximum height of the collector.



2.2.2 Maintenance duration:

Sewer networks are difficult and harsh environments where sensors become quickly dirty and fouled by biofilm, grease or particles. It generates systematic errors or wrong measurements. A periodic maintenance is thus necessary. Values recorded during the maintenance period are marked C.

2.2.3 Frequent range detection:

The frequent range gives values that are usually observed in a specific measurement site (Mourad et Bertrand-Krajewski, 2002). It ensures that the measurements fall within established limits. It is usually defined as the 95% confidence interval of the observed values. The limits of this range are set and adjusted gradually using available information and former knowledge for all parameters. Values outside of frequent range are marked B.

2.2.4 Signal gradient test:

This test detects sudden or erratic increase or decrease of values, or unrealistic gradients. It may depend on specific circumstances (dry or wet weather conditions) or on sensor type e.g. the turbidity signal, even in dry weather presents rapid and significant changes corresponding to real changes in effluent quality.

2.2.5 Smoothing method:

It has been mentioned previously that high gradients can usually occur when a sudden change in the behaviour of a system occurs, due either to a sensor fault or to a non-representative phenomenon. In order to have a smoothed signal, it should be filtered. In our case, this method is applied to filtering noisy turbidity data.

3 RESULTS AND DISCUSSION

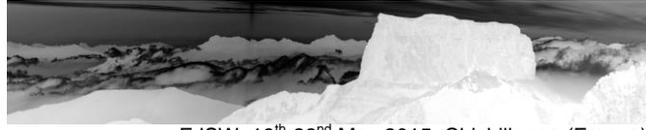
3.1 Examples of the application of the data validation procedure

3.1.1 Gradient detection and application of the smoothing method

The problem of signal gradient is general for turbidity data. All turbidity data are noisy when only a few faults have been detected by the signal's test gradient for other parameters. Ruban et al. (2008) indicated that these noises are due to measurement artifacts associated with partial and temporary occlusion of the measuring beam with large particles or by stringy. Aumond et Joannis, (2006) proposed an effective method of filtering noise turbidity. This is a real-time filtering using an algorithm which is directly incorporated into the data logging system. This method is not applicable in our case because the Hach Lange SC1000 system does not allow doing this operation. We used the moving average method which is given by the formula:

$$y [i] = \frac{1}{M} \sum_{j=0}^{M-1} x[i + j] \quad (1)$$

where $x []$ is the input signal, $y []$ is the output signal, and M is the number of points used in the moving average. The use of a value $M = 9$ has given satisfactory results (Figure 4). By applying the filter, the diurnal pattern of the turbidity variation becomes more visible with the flow rate variation,



especially during dry weather. It can also be seen in this figure the influence of rainfall events which correspond to a decrease of turbidity and an increase of flow rate.

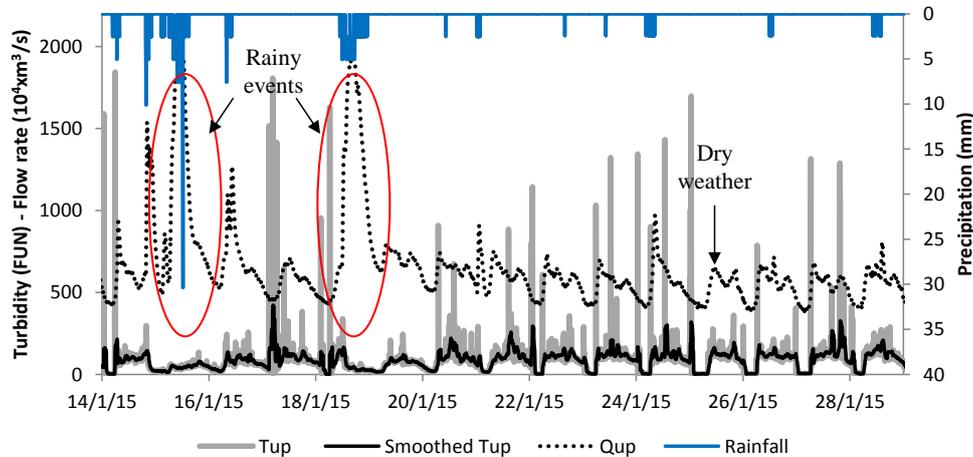


Figure 4: Example of application of turbidity data filtering

3.2 Statistical results

The flows on the three points have been monitored continuously since mid-April 2014. Statistical studies were performed on the water level and velocity validated data until the end of November 2014 in order to study their variability depending on the seasons and the events (dry or wet weather). Median values of water levels and velocities are shown in the Table 1.

Table 1: Water level, velocity and daily flow rate ranges for 2014

		Water level (m)					Velocity (m/s)			Daily flow rates (m ³ /s)					
		Hus.	Hus/ Dus	Hbr	Hbr/ Dbr	Hd.	Hds/ Dds	Vus	Vbr	Vds	Qus	Qbr	Qds	Qus + Qbr	ADR error
Spring 2014	DW	0.48	21%	0.15	8%	0.37	17%	0.19	0.30	0.31	4682	1465	5535	6147	11%
	WW	0.54	24%	0.20	11%	0.43	19%	0.18	0.30	0.37	4990	1604	6323	6594	4%
Summer 2014	DW	0.47	21%	0.14	8%	0.33	15%	0.21	0.24	0.31	3728	1485	5180	5213	1%
	WW	0.49	22%	0.16	9%	0.35	16%	0.27	0.24	0.29	4307	1548	5659	5854	3%
Autumn 2014	DW	0.52	23%	0.16	9%	0.34	15%	0.20	0.31	0.35	4155	1780	6702	5936	11%
	WW	0.63	28%	0.25	14%	0.53	24%	0.20	0.29	0.36	4529	1970	6686	6499	3%

For the three seasons, the median values of water levels ranged from 0.47 to 0.52m upstream; 0.15 to 0.16m on the branch and 0.34 to 0.37m downstream. During summer periods, the heights are lower than in spring and autumn. Whatever the season and the rainfall, the upstream velocity is always lower than the branch and downstream ones. The velocity ranges from 0.18 to 0.27m/s upstream; from 0.24 to 0.32m/s in the branch, and from 0.31 to 0.36m/s downstream. For daily flow rates, the influence of the seasonal variability was noted. It is marked by a sharp decline during the summer, up to 20% upstream. This is due to the fact that a part of the Nantes population is absent during this period. Taking into consideration the principle of conservation of mass, daily downstream flow rates and the sum of daily upstream and branch flow rates were compared. It has been noted that the average daily relative errors (ADR) do not exceed 11% for all studied events. This value corresponds to the quotient of the absolute error to the true value of the downstream daily flow relative to the sum of upstream and



branch daily flow (3). One explanation for these errors could be that the presence of sediment at the bottom has not yet been taken into account in the calculation of the wet area and therefore of the flow. The flow rates are calculated by the relation:

$$Q = S \times V \quad (2)$$

where S is the wet surface and V is the velocity.

The average daily relative errors is given by the formula:

$$ADR = \left| \frac{[Q_{ds} - (Q_{us} + Q_{br})]}{Q_{ds}} \right| \quad (3)$$

Wastewater quality monitoring began in mid-July 2014 so annual statistics cannot be made yet. However, various evolutions were noted for temperature, conductivity, pH. The temperature values ranged from 13 to 25°C between mid-July to December 2014. In this range, the biological activities is favourable in sewer network (Ashley et al., 2004). The pH ranges from 5 to 8.5. This point is important because, for this pH range, the sulphate reduction by sulphate-reducing bacteria producing sulphide can occur, leading to the concrete corrosion in sewer network (Ashley et al. 2003). The average conductivity values ranged from 824 to 1119 $\mu\text{S}/\text{cm}$ in the three points. They are consistent with previous results obtained either in Nantes (Valeyre et al., 2013) or in Nancy (Lebonté et al., 2007).

Figure 5 compares the variations of the conductivity, pH, temperature and water height for the upstream location. A daily pattern of variation of conductivity, pH and temperature is visible in dry weather. It can be noticed the influence of the rainfall on the conductivity and the temperature. The dilution by rain water decreases the concentration of the dissolved ionized substances in the wastewater and reduces the conductivity. The data acquisition has now to be continued to encompass the seasonal variations.

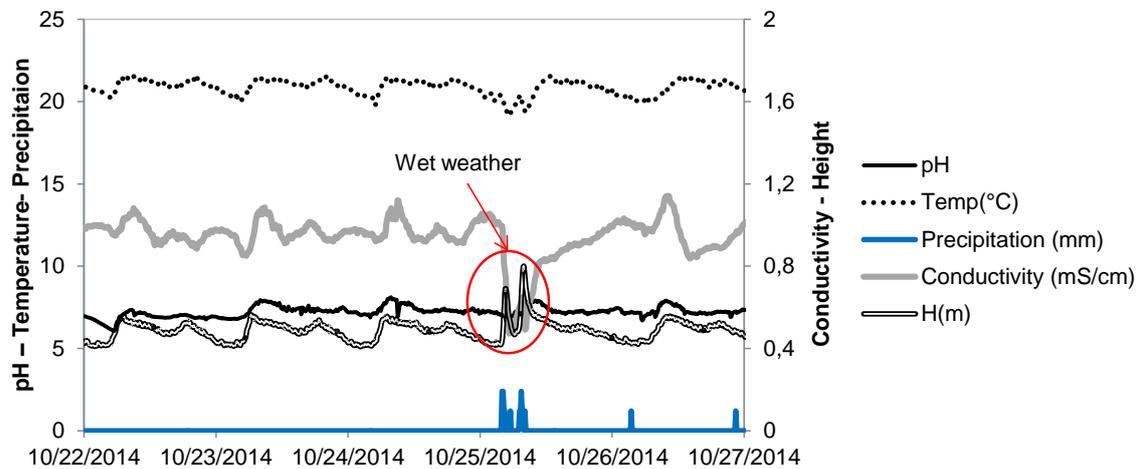
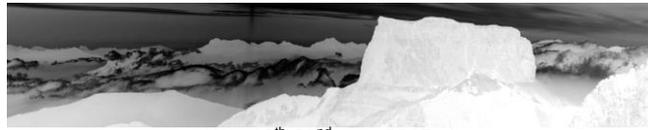


Figure 5: Evolution of the conductivity and the pH and the temperature.

4 CONCLUSION

This paper presents some results for wastewater quantity and quality monitoring in order to study the temporal and spatial representativeness of flow and pollution discharge measurements. The study showed that reliability of the used sensors remains frequently insufficient under the severe conditions that prevail in sewer systems. The measurements are subjected to several problems, like noise, outliers and missing values. The necessity of data validation was proved for detecting and optionally



correcting faulty data. Some ranges of quantity and quality wastewater parameters are determined. However, results have to be examined critically due to the lack of available data. A longer dataset would be desirable to allow a statistical analysis of the results and to verify identified phenomena. Future data on spatial representativeness of velocity and concentration will enable to better understand the measurements variations under daily, seasonal and rain-related disturbances.

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